National Bureau of Standards

TECHNICAL NEWS BULLETIN

VOLUME 34 APRIL 1950 NUMBER 4

Recording Microwave Refractometer

An instrument that measures and records small differences in frequency between two resonant cavities has been developed by George Birnbaum at the National Bureau of Standards.[1] In its present form, the new instrument can be adjusted over a wide band of microwave frequencies for measurement of dielectric constants of lossless gases and changes in the dielectric constant of such gases and very low-loss liquids and solids. Its extremely high sensitivity permits operation with small test samples. The microwave refractometer should be readily adaptable to manufacture as a field model, since the microwave components and electronic circuits are straightforward and compact. It has direct application in several fields of scientific research and industrial production, providing a convenient method for continuous monitoring of impurities in gases or liquids and for rapid testing of small solid samples. It could also be used as an ultramicrometer and to measure the thermal expansion of cavity materials.

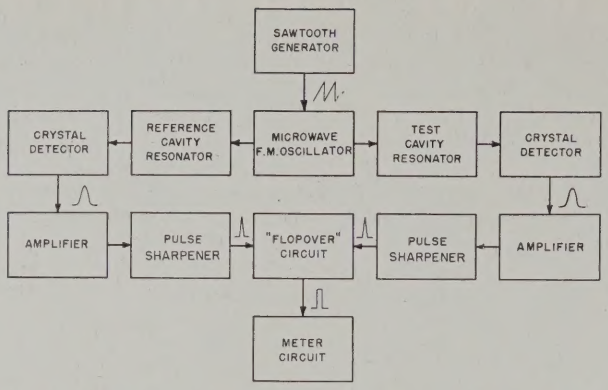
The key operating principle of the refractometer is the comparison of two cavity resonators. A test sample (gas, liquid, or solid) is introduced into one of two otherwise identical cavities. The resultant difference in resonance frequency between the two cavities is then a measure of the dielectric constant of the test sample. Tests have shown that the sensitivity of the present instrument under laboratory conditions is 200 cycles per second at an operating frequency of 9,000 megacycles.

A klystron oscillator is used as a microwave signal source and is frequency-modulated with a saw-tooth wave. The radio-frequency output from the klystron is fed to a T-junction, which sends equal parts of the signal to the two cavity resonators, one functioning as a test cavity, the other as a frequency reference. The cavity outputs are then fed through identical crystal detectors, amplifiers, and pulse sharpeners. The pulse pairs, repeated at a rate determined by the saw-tooth frequency, then go to a trigger circuit. The first pulse turns it on, and the second turns it off. The output of the trigger circuit is a rectangular wave with constant amplitude but variable width. The average value of this wave, as measured in a meter circuit, is then directly proportional to the frequency difference between the two cavities, provided that the "on-time" of the trigger circuit is also directly proportional to the frequency difference. The electronic circuits have been designed to give this linear relation between time and frequency.

In calibrating the microwave refractometer, it is desirable to use rare gases, such as argon or helium, whose dielectric constants have been measured very precisely at optical frequencies. However, for greater convenience in actual operation the reference cavity has been equipped with a tuning plunger calibrated essentially in terms of the gas pressure in the test cavity.

1 For further technical details, see Recording microwave refractometer, by G. Birnbaum, Rev. Sci. Instr. **21**, 2 (1950).

877964—50



Block diagram of recording microwave refractometer.

The maximum sensitivity that can be achieved by the refractometer is determined by its short-time stability, which depends essentially on background noise. Long-time stability depends chiefly on variations in temperature difference between the two cavities and the drift in center frequency of the klystron with temperature. When long-time stability is needed, both of these effects can be controlled by proper temperature regulation.

With solids and liquids, very high sensitivity to small changes in dielectric constant could be obtained by filling the entire test cavity with the material. But, except in the case of practically lossless substances, this would seriously decrease the Q of the cavity. On the other hand, if only a small fraction of the cavity volume

TECHNICAL NEWS BULLETIN

U. S. Department of Commerce

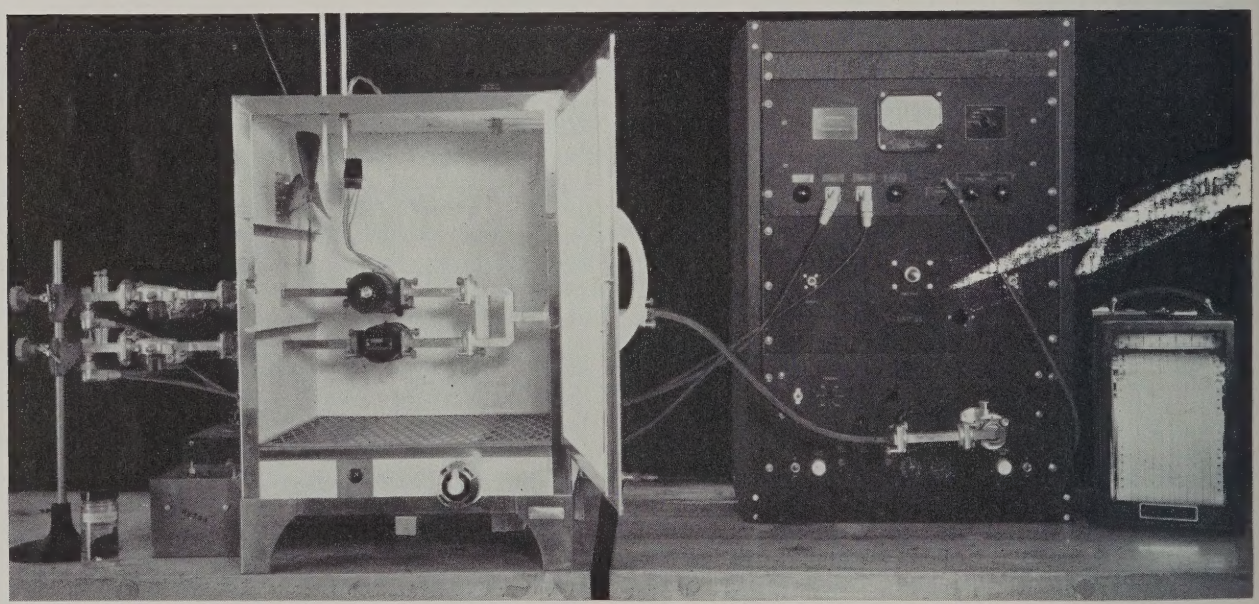
Charles Sawyer, *Secretary*

National Bureau of Standards
E. U. Condon, *Director*

APRIL 1950 **Issued Monthly** **Vol. 34, No. 4**

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Subscription price, domestic, $1.00, a year; foreign, $1.35; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, February 3, 1950.

Recording microwave refractometer 45
Round-the-world radio signals 47
Belvoir radio propagation field station 48
Corrosion of metals underground 48
Research in applied optics 50
Field X-ray development program 55
NBS publications 56



The recording microwave refractometer as used to measure the refractive index of an artificially controlled atmosphere. A klystron oscillator with its associated sawtooth generator occupies the lower panel of the cabinet at right. The klystron output, frequency-modulated with a sawtooth wave, is fed through a flexible waveguide to a T-junction inside the temperature-controlled cabinet (center). The T-junction divides the signal between two cavity resonators, test and reference, respectively. The cavity outputs are passed through crystal detectors (left) and then back through coaxial lines to identical amplifier and pulse sharpener circuits (top panel, right). The combined output is graphed by the recording meter (far right).

is occupied by a low-loss substance (a small-diameter cylinder is convenient for this work) the Q would not be appreciably affected, and sufficient sensitivity would be maintained. The position of the sample with respect to the electric field in the cavity will determine the sensitivity of the refractometer to changes in dielectric constant. Small liquid samples can be measured in the same way by placing the liquid in a quartz tube.

The restriction to low-loss materials is necessary because the present equipment is sensitive to changes in the Q of the test cavity. However, a direct extension of present techniques would avoid this limitation completely and permit simultaneous recording of changes in dielectric constant and loss.

In measuring the dielectric constants of gases, it is often convenient to use a flow technique in which a continuous stream of gas is drawn through the test cavity. This method has actually been used in a preliminary experiment to record variations in the dielectric constant of an artificially controlled atmosphere.

Similar measurements of the atmosphere are needed in radio propagation and meteorology. The recording microwave refractometer is now being studied for possible application to measurement of atmospheric refractive index. Such measurements might help to explain how high radio field intensities are produced at great distances by atmospheric scattering and "duct" processes. Many of the radio observations thus far made at frequencies above 30 megacycles cannot be explained by the ordinary refraction and diffraction calculations. Above 30 megacycles the change in refractive index with altitude and the fluctuations in refractive index in any small region of the atmosphere have a direct effect on radio propagation.

Round-the-World Radio Signals

Very low frequency radio signals traveling completely around the world have now been detected by Jack N. Brown of this Bureau.[2] The signals, transmitted from the Naval Radio Station NSS at Annapolis, Md., on a frequency of 18 kilocycles with a power of 350 kilowatts, were received at the National Bureau of Standards radio propagation field station at Sterling, Va., about 50 miles away. Normal delay time for a round-the-world signal was more than a tenth of a second, and maximum signal intensity was observed at sunset.

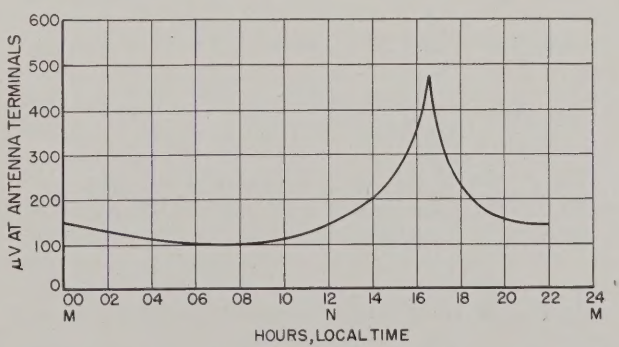
The round-the-world signals were received, with the aid of a large loop antenna 150 feet high, on a tuned-radio-frequency receiver. A dual-beam oscilloscope was connected ahead of the detector stage in the receiver so that the actual unrectified r-f envelope was displayed on the 5-inch screen along with an 18-kilocycle reference voltage. The delay time of the round-the-world signals was measured by making a moving film record of the oscilloscope screen.

The test signal transmitted from NSS consisted of a series of dots, each dot followed by a quiet period equal in duration to five dots. The test tape was transmitted at normal sending speeds, so that the pulse length of each dot was about 40 milliseconds with a repetition rate of four pulses a second.

During the winter months when these tests were conducted, the delayed signal was visible throughout the entire day. Observations of field intensity over several 24-hour periods disclosed the striking sunset maximum. A sharp peak in signal strength at 4:30 p. m. corresponded to optical sunset at the place of transmission and reception. It is an observed fact that low-frequency signals are severely attenuated when their path crosses a sunset zone. Any round-the-world signal must cross a sunset zone except during that portion of the day when the sunset zone is at the transmitter-receiver location. This explains the relatively greater strength of the signals at sunset in the transmitter-receiver location.

Delay times were measured on two different occasions under widely differing ionosphere conditions. Measurements were made first during a severe ionosphere storm, and a second set of measurements were made on a normal day. The average delay time during the storm was 0.1365 ± 0.0005 second, but on a normal day the average was 0.1373 ± 0.0005 second. The shorter delay time during a storm may be explained by the slightly lower effective height of the reflecting layer of the ionosphere under the influence of corpuscular bombardment from the sun. In any case the average values indicate a shorter propagation path for low-frequency signals during an ionosphere storm.

The transmission of radio waves over long distances may be thought of either as the propagation of a "guided wave" between the concentric spherical surfaces formed by the earth and the ionosphere, or as successive multiple reflections from the earth and the ionosphere. Within the limits of a ray approximation, both pictures yield the same results. For the delay time on a normal day (0.1373 sec) the number of hops corresponding to an ionosphere height of 65 kilometers is 55 for one trip around the earth. The length of each hop is thus 728 kilometers and the angle of take-off is 8 degrees.



The received intensity of low-frequency round-the-world radio signals shows a striking diurnal variation with a maximum at sunset.

[2] For further technical details see, Round-the-world signals at very low frequency, by Jack N. Brown, J. Geophys. Res. 54, 367 (1949).

Belvoir Radio Propagation Field Station

A new radio propagation field station that will make continuous measurements of radio waves reflected from the upper atmosphere has been established at Fort Belvoir, Va., by the National Bureau of Standards. The Belvoir Field Station, made possible by the cooperation of the Army's Corps of Engineers and Signal Corps, is one of a system of 14 stations operating under the supervision of the Bureau's Central Radio Propagation Laboratory as part of a world-wide network of over 50 radio observatories.

The station, occupying some 10 acres of countryside near the Potomac River, 13 miles south of Washington, consists of four separate buildings designed for ionospheric and geophysical measurements. Equipment at the new field station includes the latest in field-intensity recorders, ionospheric recorders, and visual recording magnetographs. The new installation is continuing, on an improved basis, work begun by this Bureau more than 20 years ago. Data gathered at the new station will be used in the preparation of predictions, 3 months in advance, of the best frequencies for short-wave radio communication, as well as warnings of sudden radio disturbances.

The Belvoir Field Station also serves as a training center in the techniques of ionospheric and field-intensity measurements. The station is a testing ground for evaluating the performance of new measuring equipment and procedures proposed for use at all of the Bureau's radio field stations. Special engineering projects are already under way to improve further the ionospheric measuring techniques.

Corrosion of Metals Underground

Much valuable information on the resistance to underground corrosion of a wide variety of ferrous and nonferrous metals and alloys has resulted from field experiments [3] now being analyzed by I. A. Denison and M. Romanoff of this Bureau. Approximately 3,000 specimens of representative pipe materials, exposed to soil corrosion for periods up to 14 years, have been examined, and the loss of weight and depth of pitting have been measured and interpreted. Because of the broad range of environmental conditions commonly encountered in underground construction, the specimens were buried at 15 test sites widely separated throughout the United States.

In order to evaluate the practical importance of soil corrosion, this Bureau began a long-term field investigation of this problem in 1922. At that time little was known concerning the useful life to be expected of underground structures for the transmission, distribution, and storage of water, gas, and liquid fuels. In the absence of information on the corrosiveness of soils, the occasional failure of metals underground was attributed to the discharge of stray electric currents in the earth or to factors, such as high acidity, which everyday experience had shown to be corrosive to iron and steel. Where these conditions were not present, it was generally assumed that an iron or steel pipe or a tank of standard wall thickness might be expected to last indefinitely.

The results of this early field study, however, indicated that corrosion of ordinary types of iron and steel in soils is much more general than had been supposed, and interpretation of these results in terms of modern corrosion theory, supplemented by laboratory studies at the Bureau, showed that corrosion is a natural consequence of the normal physical, chemical, and biochemical action of soils on metal surfaces. These conclusions were later confirmed by extensive examination of underground pipe lines and correlation of the observed corrosion with the properties of the surrounding soil.

Having shown that the commonly used ferrous metals—cast iron, wrought iron, and steel—are subject generally to soil corrosion, the Bureau in 1932 began a second long-term field investigation of the corrosion of metals that either are inherently corrosion-resistant, such as copper and its alloys, lead, and stainless steel, or that have shown exceptional resistance to corrosion in the atmosphere or in natural waters. With the active cooperation of manufacturers, pipe-line operators, and local water and gas companies, a sufficient number of weighed specimens of each selected material was buried at the test sites to permit removal of two specimens of each kind after five successively longer periods of exposure ranging from 2 to 14 years.

Measurement of the progress of corrosion in the specimens showed that copper and its alloys with silicon, zinc, and nickel are highly resistant, as a group, to corrosion in soils that are very corrosive to ordinary iron and steel. The copper alloys, however, differ rather widely in corrosion resistance, depending on environmental conditions. For example, in soils high in sulfides, copper corroded at an appreciable rate, but low-copper brasses were very resistant. The low-copper brasses showed good resistance to corrosion as manifested by reduction in thickness and by the development of deep pits, but this advantage was offset by their susceptibility to a form of corrosion known as dezincification, which is characterized by the conversion of more or less localized areas into a deposit of spongy copper having little strength. This type of corrosion, it was found, can be prevented by the addition of a fraction of a percent of arsenic to the alloy.

[3] For further technical details, see Soil corrosion studies, 1946: Ferrous metals and alloys, by I. A. Denison and M. Romanoff, J. Research NBS **44**, 47 (1950) RP2057; and Soil-corrosion studies, 1946 and 1948: Copper and copper alloys, lead and zinc, by I. A. Denison and M. Romanoff, J. Research NBS **44**, 259 (1950) RP2077.

Specimens of pipe materials exposed to the corrosive action of the soil in field studies conducted by the National Bureau of Standards are identified upon removal from one of the test sites. From the loss in weight, depth of pitting, and other effects of corrosion on these specimens, data on the corrosion resistance of a large number of pipe materials in the many different types of soil occurring throughout the United States have been obtained and analyzed.

A number of metals and alloys proved to be corrosion-resistant in the sense that a piping system constructed of any of these materials would give long service underground provided a reasonable allowance were made for reduction in wall thickness by corrosion or penetration by localized attack. Certain steels containing high percentages of chromium and nickel were resistant to corrosion in a more absolute sense, no appreciable weight loss or pitting being detected even after the maximum period of exposure. However, it must be remembered that immunity to corrosion shown by small test specimens does not necessarily mean that a large structure of the same material will last indefinitely. The effect of expanding area on the depth of pitting, which in the case of plain iron and steel is well understood, has not yet been worked out for the high-alloy steels.

The measurements of the corrosion of wrought ferrous specimens indicate that small amounts of chromium, nickel, and molybdenum, which produce high resistance to atmospheric corrosion in the modern high-strength steels, contribute little to their corrosion resistance underground. This difference in behavior is believed to be due to the fact that conditions in soils do not favor the formation of tight, adherent rust deposits, on which the corrosion resistance of these steels in the atmosphere depends.

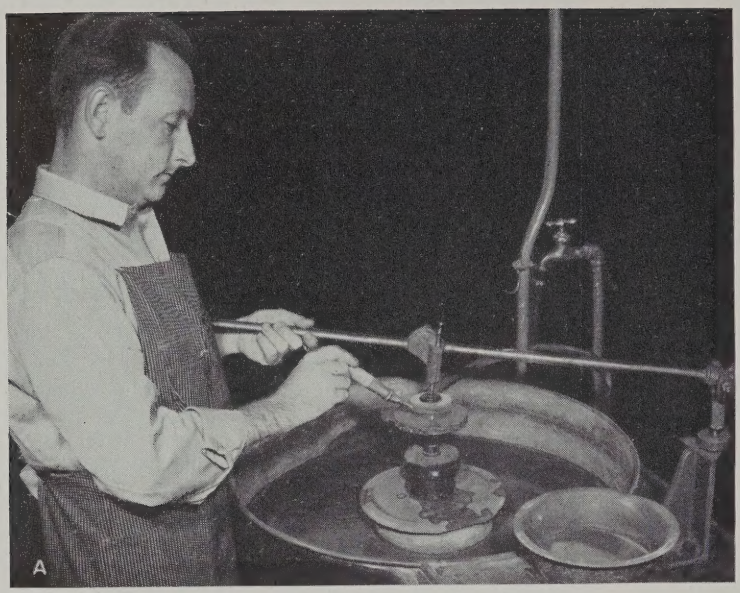
Depending on environmental conditions, the progress of corrosion with time was found to range from cessation after a short period to continuance at a rate proportional to the duration of exposure. A high initial rate of corrosion that soon decreases may not shorten the life of a buried structure as much as a low initial rate, which shows little or no decrease with time. The one environmental condition that has a predominant influence on pitting and weight loss with time is aeration. Because the initial rate of corrosion of metals in soils is in general determined by the accessibility of oxygen to the metal surface, this rate must necessarily be considerably greater in well aerated soils than in a poorly drained soil deficient in oxygen. However, oxygen in excess of that required for depolarization of hydrogen causes the formation of layers of corrosion products in close contact with the corroding areas, with the result that the corrosion rate is soon substantially diminished, if not actually reduced to zero. On the other hand, in a soil containing no more oxygen than is required to maintain a low rate of depolarization, the products of corrosion diffuse outward into the soil with little or no effect on the corrosion rate. In the Bureau's studies, the corrosion of iron, steel, copper, lead, and zinc has been expressed by a single empirical equation in which one constant is the initial rate of corrosion and the other expresses the progress of corrosion with time.

The change in the rate of corrosion of metals with time is of considerable practical importance. In soils in which the corrosion rate of a metal rapidly diminishes with time, an efficient means of combating corrosion is to provide adequate thickness. If, for example, a section of pipe is exposed to conditions that soon induce a virtual cessation of corrosion rate, the life of the pipe might very well be made infinite simply by doubling the wall thickness. On the other hand, if by doubling the thickness of the metal, only a twofold increase in useful life could be secured, the cost of the extra thickness would not be economically justified; and some other means of combating corrosion, such as a protective coating, would be indicated.

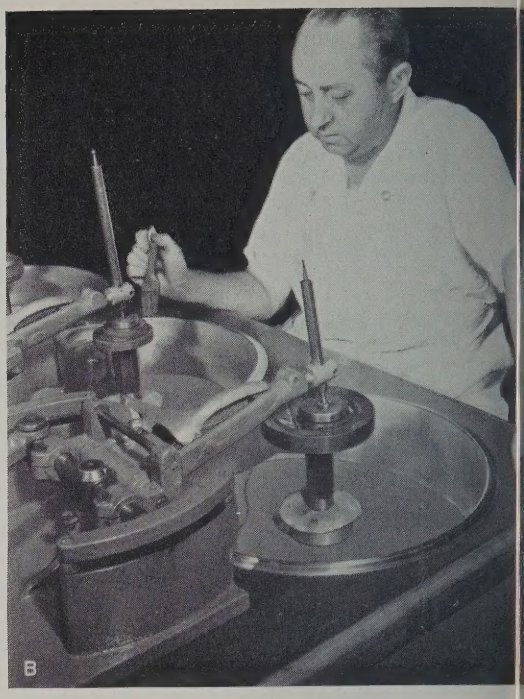
Absolute Measurement of Resistance

The first definitive results of a new method for independently checking the stability of the standard of electrical resistance in terms of length, time, and the permeability of free space are described in detail in a new paper. Resistance of an accurately computed mutual inductor was measured in terms of its inductance and frequency by use of Wenner's commutated direct-current method.

Research Paper RP2029, *An Absolute Measurement of Resistance by the Wenner Method*, 69 pages, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 30 cents a copy.



Grinding a telescope lens in the Bureau's optical shop. The grinding tool, a cast-iron disk having a surface of the desired curvature, is mounted on a slowly rotating vertical spindle and covered with an abrasive. The surface of the glass blank to be ground is pressed down against the tool by means of a pin with ball end that fits into a depression in the center of a metal "button" waxed onto the blank. As the glass disk rotates about the pin because of its contact with the rotating tool, the operator, by means of the long lever pivoted at the right, pushes the spinning disk back and forth across the tool. This combination of rotation and translation produces uniform abrasion over all parts of the lens surface. (First step in a series showing production of a small achromatic telescope objective.)



A telescope objective must be polished so preci that the finished surface does not depart from re larity by more than six millionths of an inch. T is done by means of a rotating pitch surface pres into the proper curvature and charged with ro and water. The lens, cemented to a small m disk, is pressed down against the pitch-covered by a pin that fits in the center of the metal d Lateral motion of the pin support swings the back and forth across the tool as it rotates. N that the surface of the pitch is marked off squares by grooves that receive excess polish materials. (Second step in the series.)

Research in

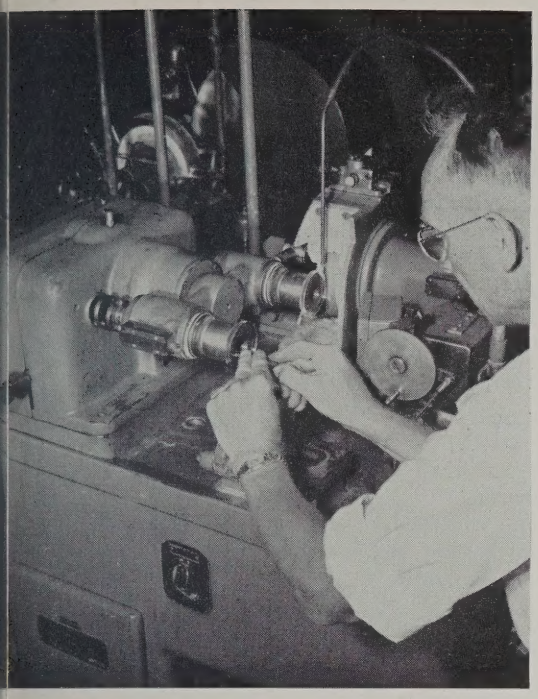
A broad program [4] of optical research and development, basic to the production of all types of optical instruments, has been carried on at this Bureau since its founding in 1901. This work has resulted in the establishment of procedures for measuring and specifying the characteristics of photographic lenses, the development of military optical fire-control devices and methods for testing them, the construction of very large optical elements for supersonic wind tunnels and astronomical work, and the development of methods of high-precision refractometry and standards of refractivity for use in the food, paint, drug, and other industries.

Optical instruments include not only those instruments developed for making measurements within the field of optics but also numerous devices that serve as tools in other scientific work and in commercial and industrial applications. Within the first group, many of which have found important commercial uses, are spectrometers, polarimeters, interferometers, refractometers, and diffraction gratings. In the second and much larger group are astronomical telescopes, microscopes, binoculars, surveying instruments, motion-picture projectors, and airplane camera lenses. An outstanding characteristic of all optical instruments is the high precision necessary in their operation. This requires extremely accurate design and construction of all optical and mechanical parts.

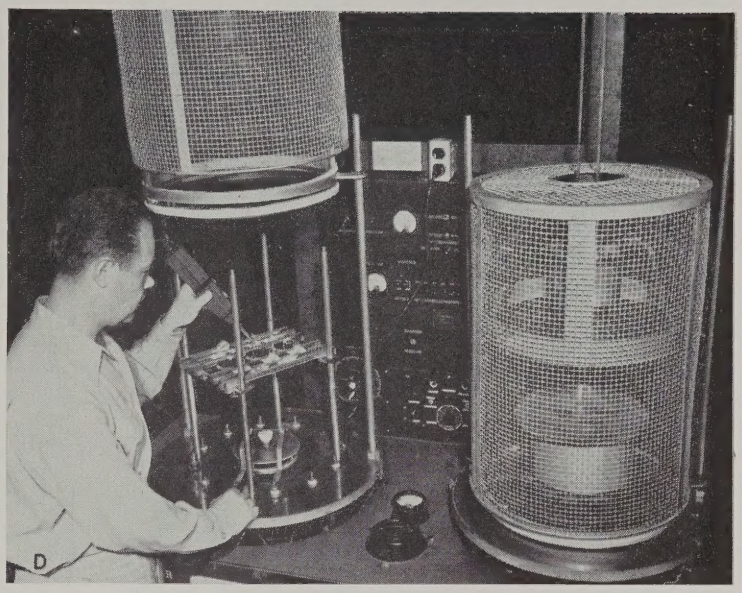
In both world wars, the requirements of the Armed Forces for optical fire-control instruments resulted in a tremendous increase in domestic production of optical glass and optical instruments. Indeed, the peacetime requirements for precision optical instruments are almost negligible in comparison with the need for military optical instruments in wartime. The American optical industry was thus obliged to expand enormously during the two wars. Similarly, the demands made on the National Bureau of Standards increased greatly, and many new instruments and new optical glasses were developed at the Bureau.

In view of this apparent need for rapid expansion of the optical industry in wartime, the National Bureau of Standards, with the cooperation of the armed

[4] For further technical details see, Research and development in applied optics and optical glass at the National Bureau of Standards, by Irvine C. Gardner and C. H. Hahner, NBS Miscellaneous Publication M194 (1949).



l is customary to make a lens oversize in order tat the edge may be finished after the surfaces lve been polished. This operation also centers te edge with respect to the axis of the lens. After te lens is correctly centered on the rotating spindle i the left foreground, the two spindles will be in-trchanged so that the edge of this lens may be found true on the large diamond-charged wheel the operator's right. Meanwhile, the lens at-tched to the second spindle is undergoing the edg-ig operation. Accuracy of centering is tested by observation of images reflected from the two sur-fces of the lens. (Third step in the series.)



Application of a low-reflecting coating of magnesium fluoride to the lens components of a telescope objective reduces light losses by reflection. This process is carried out by heating the magnesium fluoride in a vacuum (bell jar) with the lens components so that it is vaporized and condenses on their exposed surfaces. By means of oil diffusion pumps, the air is removed until the pressure is less than one-thousandth of a millimeter of mercury, and the magnesium fluoride is then volatilized. The process is stopped when a thickness of four millionths of an inch (one-fourth the wavelength of light) is formed. (Fourth step in the series.) The final step (not shown) consists in cementing together lens components of two different kinds of glass to form an "achromatic" telescope lens that will focus light of all colors at the same point.

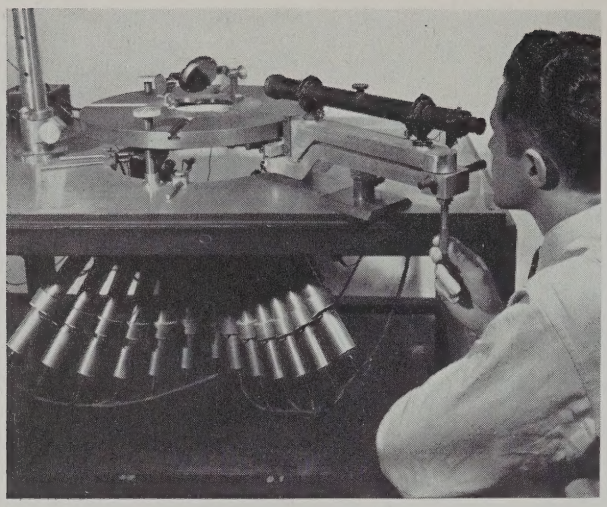
plied Optics

services, has conducted since World War I a continuing, integrated program of research and development in the optical sciences. The Bureau is able to render such service because it is the only scientific institution in the world that has, entirely within its own organization, complete facilities for making an optical instrument, beginning with the raw materials and producing in turn the glass, the optical design, the lenses and prisms, the mechanical parts, and, finally, the finished instrument. A certain portion of this program is necessarily restricted to military applications, but the greater part of the results are of broad interest in such fields as photography, television, astronomy, sugar chemistry, aerial mapping, surveying, and aerodynamics.

Photographic Lenses

The Bureau's work on photographic lenses has played an important part in placing photography—once largely an empirical art—on a more exact, quantitative basis. Although the Bureau has conducted research on the theory and methods of lens design for almost 50 years, the work on photographic lenses really began at the close of World War I, when the Army Air Corps submitted several captured German airplane camera lenses for investigation. Soon after, the Government mapping services and the military agencies became interested in photogrammetric methods, by means of which both cadastral and topographic maps can be made from airplane photographs. As the science of photogrammetry, with its exacting requirements for aerial camera lenses, advanced from this early beginning, the Bureau constantly improved methods for measuring the characteristics of these lenses.

To be suitable for photogrammetric use, an airplane camera lens must have good resolving power and little or no distortion over the entire field. The Bureau therefore initiated the development of methods for measuring and specifying these characteristics. The measurement of distortion in a lens as the linear displacement of the image point from its distortion-free position—a value convenient for direct interpretation—was substituted for the older percentage method of des-



A new precision camera calibrator recently developed by the National Bureau of Standards is tested for accuracy in the Bureau's optical instruments laboratory. The test involves determination of the angular deviation between collimators in the collimator bank beneath the table. Light from any two adjacent collimators is reflected by a biprism mounted above the hole in the circular plate in such a way as to produce an image in the eyepiece of the telescope when the proper angular difference exists between the two collimators. The adjustment necessary to bring the image into the field of view in the telescope, as read on the micrometer below the eyepiece, indicates the amount by which the angular position of the collimators must be corrected.

ignating distortion. The Bureau also introduced the practice of measuring the resolving power of photographic lenses by a photographic method exclusively and began expressing the result in terms of lines per millimeter measured on the negative. Finally, the calibrated focal length was defined and recommended, instead of the equivalent focal length, for use with airplane cameras for map making. All of these practices have now come into general use in the United States and have been widely accepted in many other countries.

The earlier measurements of distortion were made on an optical bench, but this method became inadequate as the volume of work rapidly increased. Furthermore, laboratory tests indicated that the performance of a photographic lens must be studied by a photographic test in order to correlate results with performance in actual use. To meet this need, the precision testing camera was developed and constructed. Two negatives made on this instrument, each containing a series of 19 exposures, enable distortion, resolving power, astigmatism, and curvature of field to be assessed at 5-degree intervals across one diameter of the field of view. At first this testing camera was equipped with seven collimators, permitting a 60-degree field to be investigated. Later, as wide-angle lenses came into general use, three additional collimators were added so that a 90-degree field could be accommodated. More recently the Bureau has developed a new precision camera calibrator,[5] which has a number of advantages over the previous instruments. For example, it requires but one negative to study the entire field of a camera lens, whereas the older method required four. It is also much more compact and incorporates a number of unusual design features.

In recent years, the requirements of the Agricultural Adjustment Administration and of the Soil Conservation Service for prompt delivery of maps of large areas have greatly stimulated the establishment of engineering firms specializing in airplane photography and map preparation. This has resulted in a need for standard specifications to be used by Government procurement offices in contracts with airplane-mapping agencies. Such standard specifications are now prepared under the guidance of the American Society of Photogrammetry; they require that bids for Government contracts be accompanied by a National Bureau of Standards certificate applying to the lens and camera that the contractor proposes to use. During 1949, 447 cameras and photographic lenses for photogrammetric work were tested or certified at the Bureau.

With the development of precise quantitative relations in most phases of photographic work, a demand has arisen for the extension of similar precision to the speed marking of lenses. The method now in general use is based entirely upon the ratio of the equivalent focal length of the lens to the diameter of the aperture. This ratio—known as the *f*-number—gives no consideration to the great differences in the useful light transmitted by various lenses. These differences are the result of absorption in the glasses of which the lens elements are made or reflection and scattering at the surfaces. The introduction of reflection-reducing coatings has accentuated the variation in performance to such an extent that for a given *f*-number the light transmitted by two lenses may differ almost by a factor of two.

As a result of this situation, the method of marking the diaphragms in terms of "*t*-stops" has come into favor, and the Bureau, at the request of the Society of Motion Picture Engineers, has developed an improved method [6] for calibrating the diaphragm openings of a photographic lens in terms of this system of marking. This method, in contrast to the system that has been in use, takes into account the losses of light within the lens. It thus permits a more precise and accurate control of the amount of light admitted to a photographic film during an exposure, with a corresponding increase in the uniformity and quality of results. Such a system of marking is particularly important in color photography because of the smaller latitude of exposure of color film. However, it appears likely that the new system will eventually be extended to all photographic lenses.

Studies at the Bureau have also led to a more scientific and valid analysis [7] of the causes of uneven nega-

---

[5] See, New precision camera calibrator, NBS Technical News Bulletin **33,** 8 (1949).

[6] Calibration system for photographic lenses, NBS Technical News Bulletin **31,** 137 (1947); Calibration of photographic lens markings, NBS Technical News Bulletin **33,** 50 (1949).

[7] Extremely wide-angle lenses for aerial maping, NBS Technical News Bulletin **32,** 5 (1948).

tive exposure. It is well known that the effective exposure through a photographic lens is a maximum at the center of the negative and decreases rapidly toward the edge. Various techniques have been used in attempts to reduce this variation in image illumination, but all methods have required special photographic manipulation. The Bureau's investigation explains the discrepancies that other workers have encountered in studying the variation of relative illumination from center to edge of the focal plane, and should aid materially in the design of photographic lens systems where even exposure is important. In particular, it puts the development of extremely wide-angle lenses on a sounder basis and points the way toward substantial savings in airplane mapping.

Refractometry

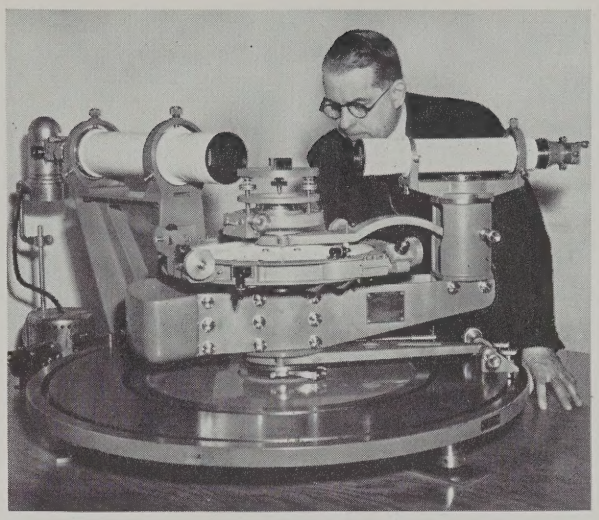
Another field in which the Bureau has pioneered is refractometry, the measurement of the index of refraction of optical materials. At the close of World War I instruments for measuring refractive index began to be produced in this country in response to the need for precise data on the optical glass manufactured during and immediately after the war. Use of these instruments increased rapidly in chemical laboratories and spread to technical applications in the sugar, oil, soap, drug, paint, ink, food, and other industries. The Bureau was then called upon to test refractometers, to formulate standard requirements for these devices, and to measure refractive indices of transparent media.

To perform these services to industry and other Government departments, the Bureau found it necessary to develop methods of high-precision refractometry in order to establish working standards of known refractivity. Use of water as a precise standard liquid in this work was made possible by accurate measurement of its index of refraction over a broad range of temperatures and wavelengths.

In recent years, infrared spectrometry has found extensive application as a tool for analysis of mixtures of organic compounds and as a means of correlating the properties of substances such as cellulose with the structure of their molecules. A knowledge of the optical properties of materials that transmit infrared radiation has thus become important. Synthetic crystals of thallium halides and of silver chloride are now available for work in this part of the spectrum, and the Bureau has extended its measurements of index of refraction to include the infrared region.[8] Values have been obtained for thallium bromide-iodide, silver chloride, and optical glass. A parallel investigation is being made of that portion of the ultraviolet spectrum that is transmitted by optical glass.

Interferometry

Precise measurements of the homogeneity—that is, the uniformity of index of refraction—of single components of optical glass are made with the interferometer. Such determinations are particularly important because variations in index of refraction establish limits for the performance of an optical system manufactured by production methods without retouching of surfaces. The Bureau has constructed and put into operation a large interferometer of 4-inch aperture, and another, of 10-inch aperture, is nearing completion. With these instruments large photographic lenses of 40- to 50-inch focal length can be examined and their performance evaluated in a manner particularly useful to lens designers. Interferometric techniques are also employed in a new precision method being developed at the Bureau for measuring the planeness of optical surfaces. In this method, a topographic map of the surface is recorded photographically. Because light waves are used as standards of length, the contour interval may be less than one-millionth of an inch.

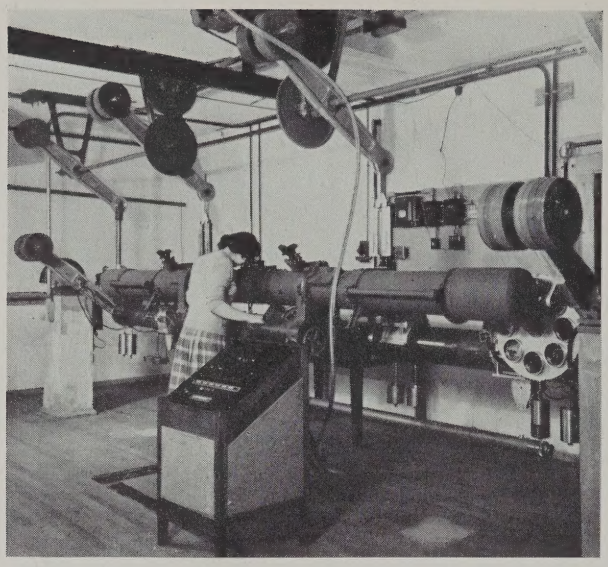


This high-precision spectrometer at the National Bureau of Standards determines the refractive index of transparent materials used by the Bureau in standardizing industrial refractometers. Monochromatic light from the source at the extreme left is rendered parallel by the adjacent collimating tube. It then passes through a 60-degree prism of the material under examination, where it is deviated through an angle that depends upon the refractive index of the prism. The deflection of the beam, as observed in the telescope at right, is read on the large graduated circle below the prism table.

Range Finders

The most complex of all optical instruments is the optical range finder, used by the armed services to measure the distance from an observer to a target. In this device, the number of residual errors that remain to be corrected is so large and the individual errors are so small and so nearly equal in magnitude, that it is impossible to separate and identify them from observations of terrestrial targets. Thus, in development work for improvement of range-finder performance, these residual errors must be studied separately in the laboratory, with adequate control of all environmental con-

[8] New crystals for infrared spectrometry, NBS Technical News Bulletin **32**, 96 (1948).



The range finder testing laboratory at the National Bureau of Standards is the only one in this country and is believed to be the most complete in the world. The testing apparatus is arranged to provide for eight distinct simulated targets (note turret with eight apertures, right) at distances from infinity to 500 yards, and for settings in elevation at 5-degree intervals from 0° (right) to 90° (left). Temperature of the test room may be maintained at any desired value between 0° and 110° F.

ditions such as temperature, exposure to directed radiation, and orientation with respect to the gravitational field.

The National Bureau of Standards has therefore built a special range-finder testing laboratory under the sponsorship of the Army Ordnance Department. Equipped with a precision collimator system that optically simulates a target for eight different ranges at any desired elevation, this laboratory—the only one of its kind in this country—provides for testing under conditions corresponding to a wide range of climate and permits the complete analysis of the behavior of a range finder with a thoroughness and facility impossible with outdoor targets.

A range finder is essentially a double-telescope system in which the entrance pupils are widely separated at a known fixed distance—the "base length" of the instrument—while the oculars are spaced for binocular use by a single observer. Range is obtained by a triangulation method, in which the rays proceeding from the target to the entrance pupils form a triangle with the base length of the instrument itself.

To obtain the necessary precision, the target-simulating apparatus must produce two collimated beams separated by the base length of the range finder (13½ to 15 feet) and departing from parallelism by an angle accurately known within ½ second. This precision must be independent of large temperature variations and movements of the apparatus to vary the apparent elevations of the target. Such rigorous requirements have been met by mounting the collimator instrument in an insulated chamber that can be maintained at any fixed temperature between 0° and 100° F. The chamber may also be subjected to a preassigned rate of temperature change. Directed radiation from the sun comparable to that received under service conditions is simulated by a cylindrical mirror of paraboloid cross section extending the length of the range finder. Enviromental conditions are thus under complete control at all times.

In the short time that the range-finder laboratory has been in operation at the Bureau, range finders of foreign origin and improved prototype models, as well as those in use by the Army and Navy, have been tested under a wide variety of conditions. Results that formerly required outdoor tests are now obtained with a great saving of time, and measurements that previously could not be made have become feasible.

As a result of this work, it has been possible to clarify the many different types of error occurring in a range finder and to make quantitative studies leading to their correction or compensation. Components of range finders have been tested separately to determine their contribution to over-all performance, and improved components having reduced errors have been developed. Range-finder design has thus been given a firm engineering basis, and the paths along which future development should proceed have been clearly indicated.

Optical Shop

To aid in the work on optical instruments, the Bureau maintains a modern optical shop. In general, this shop does not attempt to utilize production methods but specializes in making very precise optical components or custom-made optical systems in accordance with the Bureau's own designs.

Recently, the requirements of wind-tunnel optics—a new field concerned with wind-tunnel instrumentation for supersonic velocities—have created a need for large optical components of extreme precision for use in interferometers and Schlieren apparatus. Glass disks 36 inches in diameter are often employed, and even larger constructions have been contemplated. The optical shop has been called upon to make large interferometer plates, beam splitters, and aspheric lenses for this purpose. Off-axis parabolic mirrors, another type of aspheric surface now important in infrared spectrometry, have also been constructed with diameters up to 8 inches.

As interferometric methods of testing surfaces and measuring lengths are in general use throughout the Bureau, a large part of the work of the optical shop consists in supplying optical planes of various sizes and their restoration when they become badly scratched through use. In making a first-class transit theodolite, an optically plane metal blank is necessary for the graduated circle if the graduations are to be sufficiently accurate; errors should be no greater than 1 or 2 seconds of arc. The optical shop has devised methods for producing such surfaces and also for bringing the locating shoulders of a graduated circle into optical

parallelism with the surface to be graduated. During World War II the Army Engineer Board undertook the development of European-type precision transits with graduated circles not more than 4 inches in diameter. The optical shop produced the metal blanks for the circles used in the earlier instruments and also made the glass blanks required for the later models.

The making of graduated circles is but one example of the Bureau's use of precise optical methods to produce parts for use in other fields. Other examples include the production of high-precision decimeters and other length standards of fused quartz, accurate cores for inductance, and precise spheres to serve as standards of curvature.

In connection with the work of the optical shop, the principles underlying the polishing of glass are now being intensively investigated. In addition to a study of the effects of different polishing agents and methods of application, an attempt is being made to learn more about the fundamental nature of the polishing process. Each crystalline material requires a special technique for the production of an optically regular surface and a good optical polish. At present a larger number of new synthetic crystals are becoming increasingly important because of their refraction or transmission characteristics, and the development of suitable techniques for polishing them is also a matter of special study at the Bureau.

Field X-Ray Development Program

Wartime experience revealed the need for good field X-ray equipment and led to a program at the National Bureau of Standards to coordinate the development of field X-ray components for the Research and Development Branch of the Surgeon General's Office. Ordinary civilian hospital X-ray apparatus is not suitable for field service—it is too heavy and bulky, and is not rugged enough to withstand the rough handling of military use. Field equipment should combine ruggedness with light weight, using standardized components and as few separate parts as possible. These features must be embodied in apparatus that is easily assembled, simple to operate, and flexible enough to be used for diagnostic work under a wide variety of conditions. It should provide for fluoroscopic examinations, as well as radiographic work with permanent film records.

As a first practical step, a transportable X-ray table intended for radiography in forward areas was made by modifying the Army Localizer Table to provide a rigid top, a Bucky, and an attachment for horizontal fluoroscopy. For more fixed installations, a demountable tilting radiographic and fluoroscopic table was made by modifying a commercial model single-tube table. It was realized that these models were far from ideal, but they served as a starting point for further development. At a meeting of the Radiological Society in December 1947, several hundred radiologists examined these prototypes, and contributed valuable suggestions for further modifications.

Following this, in conferences at the National Bureau of Standards, the equipment specifications for service under various field conditions, the functions required in different zones of military activity, and the basic equipment designs were reviewed. Detailed specifications of the items to be developed were then submitted to the X-ray industry for consideration. Twenty companies presented proposals, and by the end of the summer of 1948 the first development contracts had been negotiated. For rapid, over-all progress it was considered desirable to divide the work among several companies. The General Electric X-ray Corporation arranged to develop a tilting radiographic and fluoroscopic table and tube stand, a full-wave 100-peak-kilovolt, 100-milliampere generator, and an X-ray tube unit. The Westinghouse Electric Corporation contracted to design an exceptionally lightweight portable X-ray unit of 85-peak-kilovolt and 15-milliampere capacity, as well as film processing equipment. The Kelley-Koett Company was awarded a contract to develop a lightweight transportable horizontal Bucky table with provision for a limited amount of fluoroscopy. Preliminary mock-up models of all these units were displayed at meetings of the Armed Services Material Group, and working models were studied by this group during the fall of 1949.

The equipment being developed by General Electric is intended for more or less fixed hospitals, and it may be used without the fluoroscopic components in land-force evacuation hospitals, aboard ship, and in overseas base hospitals. All of the major professional requirements for fixed X-ray installations are provided for, but the new designs differ from conventional ones in several ways. A novel engineering approach was adopted to reduce size and weight without sacrificing strength or function. Besides omitting functionless frills, the design distributes the structural metal to give highest strength for a given weight. Basic structures are fabricated of standard sheet metal, either aluminum or steel. The use of aluminum lightens the entire assembly and simplifies the packaging problem. A "building block" scheme has been followed so that certain components can be omitted, leaving lighter and simpler units for use in mobile installations.

The radiographic and fluoroscopic table consists essentially of a table base that links with floor-mounted side rails to support the tube stand. The base and side rails form a very stable structure, which is arranged with a single pivot to support the table frame containing a counterbalance for the fluoroscopic carriage. The table frame also carries a reciprocating Bucky diaphragm with collapsible guards to stop scattered radiation. The fluoroscopic carriage includes a spot film device and has a shutter arranged to match the maximum beam to the screen dimensions regardless of the distance from the screen to the table top. The

table may be tilted either with a variable-speed hydraulic drive or with a hand tilt mechanism and is readily disassembled into lightweight components of convenient size for handling.

The 100-peak-kilovolt, 100-milliampere, full-wave generator uses sulfur hexafluoride gas as its insulating medium. This is a radical departure from present practice of using oil insulation for high-voltage units of this class, but it has many advantages in military use. Sulfur hexafluoride is noninflammable, tasteless, odorless, and nontoxic; its density is more than five times that of air. Slight contamination of the gas with air does not seriously reduce its insulating properties, whereas contamination of oil insulation is a much more serious problem. The use of gas as insulation also means a large saving in weight and much easier handling. The generator unit employs rectified tubes of an entirely new design in which the anode structure extends to the outside of the envelope in such a way as to provide increased strength. The glass envelope is corrugated to give the necessary voltage creepage path in a shorter-than-usual tube. The tubes are further protected by shock mounting at the base of the transformer so that they can be shipped in place in the generator. If any of them should fail, the unit can be operated half-wave or self-rectified. Tilt table, tube stand, transformer, and control stand are packaged in two units, small enough to be transported on a 1-ton military cargo trailer. These packing units are watertight and will even float.

The lightweight transportable radiographic table being developed by the Kelley-Koett Manufacturing Company is for use in the forward areas of military activity. It is intended primarily for radiography but, with additional components, allows for horizontal fluoroscopy. Stretcher radiography of patients too badly injured to be moved to a table is also possible by swinging the tube unit to the rear of the table. In conventional tables, the table top itself is of light construction to keep its X-ray absorption low and depends on a heavy frame to give it the required rigidity. The new table uses a lightweight frame, deriving rigidity from a layer of woven fiberglass cemented to the undersurface of the panel. Total weight of table and accessories is only about 250 pounds.

The 85-peak-kilovolt, 15-milliampere, portable X-ray unit with mid-ground tube-transformer-head, being developed by Westinghouse, has been made as lightweight as possible, without sacrifice of performance, through the use of new designs and materials. An initial model has been designed around a commercially available X-ray tube, but further reduction in size and weight of the tube head may be made if, as is expected, a tube of smaller size becomes available. The complete tube head will weigh only about 30 pounds. Further space and weight saving are accomplished by using the space around the transformer leg, normally wasted, for a closed neoprene tube to serve as the expansion bellows required for operation over a wide range of temperatures and altitudes.

Technical supervision of the field X-ray development program has required the use of a wide range of facilities and trained personnel at the National Bureau of Standards. Complete tests of shockproof terminals, for example, have been carried out through the cooperative efforts of several specialized divisions of the Bureau. The characteristics of the different X-ray components can be carefully, quickly, and economically studied before they are sent on to the military services for field testing. Later, detailed specifications will be drawn up for tooling and manufacture so that the various units can be placed into production by any qualified manufacturer on short notice. A continuing review of X-ray equipment requirements, in the light of future technical developments and of military needs, would provide a sound basis for future plans and designs in this field, and such review is contemplated by the Bureau as part of a long-range program.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume 44, number 3, March 1950. (RP2072 to RP2081, inclusive).

Technical News Bulletin, volume 34, number 3, March 1950. 10 cents.

CRPL–D67. Basic Radio Propagation Predictions for June 1950. Three months in advance. Issued March 1950. 10 cents.

Research Papers

RP2062. Influence of the ground on the calibration and use of VHF field-intensity meters. Frank M. Greene. 5 cents.

RP2063. Determination of curvature by an osculometer. Harvey L. Curtis. 5 cents.

RP2064. A multicolumn countercurrent molecular still. Samuel L. Madorsky. 5 cents.

RP2065. Hydrocarbons in the 108° to 116° C fraction of petroleum. Augustus R. Glasgow, Jr., Charles B. Willingham, and Frederick D. Rossini. 10 cents.

RP2066. Concrete as a protective barrier for gamma rays from cobalt–60. Robert J. Kennedy, Harold O. Wyckoff, and William A. Snyder. 5 cents.

RP2067. Pulse packing in magnetic recording wire. Irvin L. Cooter. 10 cents.

RP2068. Note on the stabilization of acetylglycosyl halides and sugar acetates. Horace S. Isbell and Harriet L. Frush. 5 cents.

RP2069. Phase-equilibrium studies of the high-lime portion of the quinary system Na_2O-CaO-Al_2O_3-Fe_2O_3-SiO_2. William R. Eubank. 15 cents.

RP2070. The field generated by an arbitrary current distribution within a waveguide. J. J. Freeman. 5 cents.

RP2071. Back-scatter observations by the Central Radio Propagation Laboratory—August 1947 to March 1948. W. L. Hartsfield, S. M. Ostrow, and R. Silberstein. 10 cents.

Circulars

C483. Testing by the National Bureau of Standards. Policy, general information, fee schedule. 25 cents.

Building Materials and Structures Reports

BMS118. Stack venting of plumbing fixtures. John L. French. 15 cents.

U. S. GOVERNMENT PRINTING OFFICE: 1950